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Dynamic wake meandering modeling

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Total number of authors:
12

Publication date:
2007

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
Larsen, G. C., Madsen Aagaard, H., Bingöl, F., Mann, J., Ott, S., Sørensen, J. N., Okulov, V., Troldborg, N., Nielsen, N. M., Thomsen, K., Larsen, T. J., & Mikkelsen, R. (2007). *Dynamic wake meandering modeling*. Risø National Laboratory. Denmark. Forskningscenter Risoe. Risoe-R No. 1607(EN)

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Appendix 1: Cases

1 Nano structured material

Case 1.1: Application of Nano-sized Supplementary Cementitious Materials (SCMs) in Cement-based Materials

iNANO research project:

Jørgen Skibsted, Instrument Centre for Solid-State NMR Spectroscopy, Department of Chemistry and Interdisciplinary Nanoscience Center (iNANO), University of Aarhus.

Background

Supplementary cementitious materials (SCMs) may advantageously be employed in cementitious systems, based on Portland cement, to improve a number of physical properties such as rheology of the wet cement paste and the strength, durability and lifetime of the hardened material. Furthermore, SCMs may partly replace Portland cement in concrete, thereby reducing the costs and CO2 emission associated with the material for specific SCMs. Traditional SCMs such as silica fume, fly ash, and granulated blast furnace slag act as fillers, by entering the empty spaces between the cement grains, and exhibit pozzolanic reactions where they are partly consumed during hydration, producing hydration products similar to those from Portland cement.

Objectives

The aim of this on-going project is fundamental research on the development and structural characterization of new SCMs where the actual or modified nano-sized particle/crystallite forms are utilized to obtain either specific physical characteristics or new cementitious materials that are low in energy consumption and CO2 emission. For example, the application of specific nano-sized clay particles can significantly change the porosity of hardened cements and the rheology of the wet cement mixture, the latter improving the self-compacting properties of concrete as utilized in e.g. the production of concrete elements and concrete form work. The SCMs under investigation are primarily based on materials that can be produced with nanoscale properties from raw materials available in large deposits (in Denmark).

Experimental methods

The principal part of the research project focuses on the structural characterization of the SCMs and their interactions with the cement matrix including hydrational reactivity and effects on hydration kinetics. The structural studies are mainly performed by solid-state NMR spectroscopy, which probes local structural features on the atomic-/nano-scale for specific elements (e.g., 1H, 27Al, 29Si) in amorphous as well as crystalline components. Moreover, X-ray diffraction techniques, thermal analyses, and nanostructural tools such as atomic force microscopy (AFM) are employed in collaboration with researchers from iNANO, industry or from other academic research institutions.

Applications and perspectives

The overall goal is to develop new materials based on nano-sized SCMs with improved properties for specific applications in the cement, concrete and related industries. The sustainability of the materials is also of high priority, which is targeted by research on new cementitious materials that result in a significant reduction in energy consumption and CO2 emission. The development of such materials is required in order to fulfill the commitment on reduction in CO2 emission by 2012 stated in the Kyoto agreement.

Case 1.2: Memory Rich Walls - Intelligens og Smart Materials i byggeriet

Mette Ramsgård Thomsen, lektor og leder af Center for Information teknologi og Arkitektur. Kunstakademiet Arkitektskolen

Henrik Hautop Lund, professor og leder af AdapTronics Group, Maersk Mc-Kinney Moller Institute for Productions Technologies, Syddansk Univeritet, Danmark.

Peter Sommer Larsen, seniorforsker på Danish Polymer Centre, Forskningscenter Risø.

Lars Steffensen, arkitekt MAA og partner på Henning Larsens Tegnestue.

Background

Nanoteknologi og brugen af smart materials har gennem det sidste årti udviklet sig fra rene fremtidsscenarier til en reel mulighed for anvendelse og implementering.

Smart materials er materialer, der kan indeholde tilstandsskift såsom farve, translucens eller formændringer. Dog er det stadig uudforsket hvordan de for alvor integreres i en bygge- og designkontekst. I byggeindustrien er der en voksende interesse for smart materials, men meget lidt viden omkring, hvordan disse materialer kan behandles og detaljeres.

Memory polymers er materialer som reagerer med form- eller størrelsesændringer på udefra kommende stimuli som lys eller varme, men også kontrollerede signaler som magnetiske eller elektriske impulser. Materialerne er karakteriseret ved deres mulighed for at 'huske' deres oprindelige form. Stræk varme kan deformere materialet og giver det en ny form. Denne form er opretholdt, indtil materialet genopvarmes, hvorefter det, ved at frigive fastholdt elastisk energi, kan vende tilbage til sin originale form. Højteknologiske produkter som mobiltelefoner, bio-medicin, luft- og rumfart, professionelt sportstøj og emballage er begyndt at efterforske brugen af memory polymers. For eksempel eksperimenterer man i medicin med brugen af spundet memory polymers i kirurgisk sytråd til støtte for nøglehulskirurgi, hvor sytrådens krumning kan styres gennem elektriske impulser uden for kroppen. Tilsvarende, men i en anden skala, er man i luftfartsindustrien i gang med at udvikle fly vinger, der skifter form under flyvning og dermed kan tilpasse sig aerodynamiske forhold.

Indenfor arkitektur og design er der meget få eksempler på hvordan disse materialer kan anvendes. I Hanabi Lamp [1] undersøger den Japanske design gruppe brugen af memory polymers i en dynamisk lampeskærm der åbner sig idet lyset opvarmer skærmens materiale, mens i Grado Zero Espace's [2] sportsjakke reagere en membran af memory polymer på skift i de klimatiske forhold, både i omgivelserne og på kroppen, således af kroppen kan ånde frit. I arkitekturen er der stadig ingen eksempler på hvordan memory polymers kunne blive implementeret.

Innovation/new possibilities

Memory Rich Walls afsøger de potentielle skæringsflader, der opstår i konceptualiseringen af en intelligent overflade og dets beboelse. Ved at sammenholde erfaringer fra arkitektur, robotteknologi og polymerforskning

undersøger Memory Rich Walls bygningskroppen som autonomt system. Projektet undersøger muligheden for at lave en dynamisk væg-membran der indeholder tilstandsskift. Inspireret af forestillingen om en dynamisk arkitektur, undersøger Memory Rich Walls hvordan vores omgivelser kunne tilpasse sig skiftende programmatiske og funktionelle forhold såvel som klimatiske, energimæssige og akustiske forhold.

Brugen af dynamiske konstruktioner bliver mere udbredt i nutidig arkitektur. Sportsstadioner, som for eksempel Herzog og de Meurons stadion for Olympiaden i Beijing 2010, har bevægelig overdækning, der muliggør skift i klimakontrol og –afskærmning [3]. Under konceptet intelligente facader har arkitekter og ingeniører forsket og udviklet nye former for dynamiske membraner, der muligør en automatisering af solafskærmning og ventilation. I det Arabiske Institut i Paris af Jean Nouvel skaber en dynamisk solafskærmning af små motoriserede linser en dynamisk væg der reagere på skiftende lysforhold [2].

Disse eksempler bruger alle traditionelle mekaniske teknologier til at effektuere tilstandsskift, men i og med at der opfindes nye materialer og teknologier åbnes der op for helt nye formgivnings- og anvendelsesmuligheder. Denne udvikling vil tilmed lede til et forandret arkitektonisk sprog og tænkning.

Objectives

Memory Rich Walls undersøger:

- Hvordan memory polymers kan resultere i gentænkningen af almindelige arkitektoniske elementer, vægen, såsom skillevægge, vinduer og døre.
- Hvordan memory polymers kan bruges i sammenhæng med gængse byggematerialer som træ, stål, tekstil og andre plast fiberbaserede materialer.
- Hvilke muligheder, der er for at kontrollere memory polymers gennem sensorbaseret programmering?

I Memory Rich Walls tager vi væggen som problem. Eftersom byggeriet i stigende grad henvender sig til et flydende arbejdsmarked, hvor kravene til et fleksibelt og re-konfigurerbart arbejdsmiljø sætter nye behov for indretningen af arbejdszoner, afsøger Memory Rich Walls ideen omkring en dynamisk væg, hvis form, størrelse, transparens eller akustik kan ændres.

Grundlaget for projektets skalaforhold og valget af væggen som praktisk problem er at udvikle løsninger for hvordan memory polymers kan bruges i sammenhold med traditionelle bygningsmaterialer såsom træ, stål, tekstil og andre plast fiberbaserede materialer. Memory polymers er dyre materialer og det er omkostningskrævende at skabe de rette betingelser for deres aktivering. Ved at undersøge sammenføjning og detaljering af disse hybride materialer er det målet at undersøge deres praktiske brug såvel som økonomisk bæredygtighed. Endelig er formålet ved at vælge væggen som prototype, det at vi gennem en potentiel opskalering kan pege på hvordan memory polymers ville kunne bruges i bærende konstruktioner og facadeelementer.

Experimental method

Memory Rich Walls anvender en eksperimenterende og praksisrelateret metodik. Ved at undersøge detaljeringen og sammenføjningen af materialet, er det målet at skabe en 1:1 demonstrator, som kan evalueres i forhold til et identificeret scenarie der sætter designkriterier for konstruktion, akustik, klima og energiforhold. Udviklingen af 1:1 demonstratoren vil blive baseret på en række prototypestudier. Demonstratoren er forskellig fra prototyperne i og med, at den forholder sig direkte til det identificerede scenarie. Det vil sige, at det arkitektoniske program giver en kontekst for demonstratorens funktioner og indbyggede egenskaber. Endvidere er demonstratoren i et reelt skalaforhold og kan derfor evalueres i forhold til beboelse og funktion.

Possible applications and perspectives for the construction sector and society:

- Solafskærmning
- Klimakontrol
- Akustik regulering.

Partners

Memory Rich Walls er et nyt tværfagligt samarbejde mellem Center for Informationsteknologi og Arkitektur ved Kunstakademiets Arkitektskole, AdapTronics Group ved Maersk Instituttet, Syddansk Universitet, Henning Larsens Tegnestue og Danish Polymer Centre ved Forskningscentret Risø.

Projektet vil drage nytte af partnernes forskelligartede baggrunde og faciliteter. Ved at bringe arkitektur, design, robotteknologi, ingeniørvidenskab og polymerforskning sammen, vil Memory Rich Walls skabe et unikt projektgrundlag. CITA og AdapTronics Group har særegen indsigt i programmeringen af intelligente og reaktive systemer, og gennem sammenførelsen af deres faciliteter for elektrisk ingeniørarbejde [Maersk Instituttet] og rapid prototyping [CITA] vil vi kunne støtte projektets realisering. Endvidere vil samarbejdet med Danish Polmer Group give projektet direkte adgang til udviklingen og formgivningen af specifikke memory polymer typer. Endelig vil Henning Larsens Tegnestue give kontekst for at skabe scenarier, undersøge anvendelsesmuligheder og evaluere demonstratoren i forhold til nutidig arkitektur og byggeindustrielle forhold.

Target group

Arkitekter og designere både i praksis såvel som i akademisk kontekst, ingeniører, polymer forskere, robot teknologer.

Possible external actors (national and international)

Septum A/S (Skillevægsproducent)

Material Connection, international materiale bibliotek om nye materialer (Milano).

References

[1] http://www.nendo.jp/en/works/detail.php?y=2006&t=71

[2] http://nanoarchitecture.net/article/?c=shape-memory-polymers

[3] Domus 2003 (jun) Nr.860 Side 34-41

[4] Bonet, Llorenc, "Jean Nouvel”

Case 1.3: 'Flying' roof in plastic composites

The distinctive roof of the platform at Lindevang Station in Copenhagen utilizes the unique qualities of plastic composites, commonly known as fibreglass. While inspired by the Great Belt bridge, the architects found their practical solution at Fiberline Composites A/S in Kolding, Denmark.

The roof above the platform at the new Lindevang metro station in Copenhagen was a special challenge to KHRAS Architects. The idea was to avoid having any columns on the platform, yet create a lightweight structure that would not dominate the neighbourhood.

"On our way home from London, we saw the Great Belt bridge from the air and thought, 'that's how we should do it'. We drew a draft of a suspension-bridge structure, in which the roof hangs on wires between columns at its ends. However, we did not know if there were any materials that would make the idea possible in practice," says Nille Juul-Sørensen, the architect in charge of the project.

The architects found their solution at Fiberline Composites A/S in Kolding, Denmark, one of Europe's leading manufacturers of state-of-the-art profiles in plastic composites, commonly known as fibreglass.

Fiberline engineers suggested a modular roof of Fiberline profiles. The solution is based on the unique qualities of plastic composites: high strength combined with low weight plus an attractive surface finish that does not require frequent maintenance.

"We were very enthusiastic about the technical properties of the material, as well as the quality and finish we would be able to provide. The result is a roof that gives the station a distinct identity, and which we are now using elsewhere, for example on another station in Malmö, Sweden," says Nille Juul-Sørensen.

"We believe that plastic composites are a state-of-the-art building material with enormous potential – not least because plastic composites enable creation of integrated design, allowing elements such as cables, lighting, reflectors, water, etc., to be built into the actual composite modules. We are currently working on developing these perspectives," he continues.

Finished modules

The roof of the platform at Lindevang Station is 60 metres long and 7.5 metres wide. Fiberline Composites supplied it in seven sections which were assembled and glued together on site.

The great strength and low weight are a prerequisite for enabling the roof to hang in one piece, suspended by wires that are fastened to four pylons at the ends. The roof is very durable, as plastic composites do not disintegrate and require only cosmetic maintenance. In addition, the use of prefabricated modules made mounting easier and quicker.

The steel parts of the roof were supplied and assembled by LNT Industri A/S of Esbjerg, Denmark, the painting work was made by BK Allround of Fredericia, while the actual mounting was done by Pihl-Aasleff J.V.

Active partnership

At Fiberline there are expectations that Lindevang Station can be a breakthrough for the use of plastic composites in yet another area of construction.

"We believe the perspectives are virtually unlimited. As yet, very few architects and contractors have really investigated the unique possibilities the material provides. We are ready and willing to participate in development projects with all our experience and expertise in the properties and possibilities of plastic composites," says Lars Petersen, engineer, the project manager of this Fiberline project.

Fiberline has considerable experience from numerous international projects, and has developed and used plastic composites for things such as road bridges, bearing structures of building elements and glass facades. Fiberline has its own research and development department, and it is company policy to participate actively in development activities in close knowledge partnership with customers and contractors.

Case 1.4: International award for innovative GRP footbridge

The award-winning GRP footbridge near Lleida, Spain, was custom-built to demanding specifications of the Spanish railway authorities for minimal maintenance, fast installation, and zero magnetic interference.

An advanced pedestrian footbridge spanning the Madrid-Barcelona high-speed rail link has won international acclaim in the form of "Footbridge Award 2005". Situated close to the Spanish city of Lleida and formally opened in 2004, the bridge is made of high-tech glassfibre-reinforced plastic (GRP).

The bridge was designed by the Spanish engineering consultants Pedelta and built using structural components supplied by Fiberline Composites A/S, Denmark.

The award, in the category "Technology" for medium span (30m-75m) bridges, was presented by an international panel of judges. Speaking on behalf of the panel of experts, Helena Russell, editor of the journal Bridge Design & Engineering, described the bridge as "a world first, opening up a complete new field of structural design possibilities. The bridge makes excellent use of new technology to solve a number of specific problems. It combines the advantages of minimum maintenance and light weight, making it easy to transport and to erect."

As the bridge would cross a major rail link, minimising disruption to services was a key priority for the Spanish railway authorities. Accordingly, the bridge was assembled at the line side and then craned into place, resulting in a railway possession time of only three hours for the complete erection," says Dr. Juan Sobrino, Pedelta.

GRP does not conduct electricity, which is also very important as it means there is no magnetic interference with the electrified railway," continues Mr. Sobrino.

Complex geometry

The 3m-wide bridge boasts a 38m span, one of the longest in Europe for a GRP footbridge. A major challenge in the project was the construction of the two arches, which each lean approximately 10 degrees inward. The bridge therefore has no simple perpendicular components but is composed of short straight sections. The final result is a triumph both technologically and in design terms.

Pedelta chose Denmark's Fiberline Composites A/S, which specialises in GRP profiles, to develop and fabricate the structural components. The 9m long components were shipped to Spain for on-site assembly and erection.

Case 1.5: Structuring of materials by the use of nanoparticles, nanofibres, nanotubes and nanoclay

Composite materials are on the brink of making a leap with the help of nano technology; the research is vast and shows great potential. However, nothing is definite and research still awaits the technologies and processes that will make nanoscale work to create better properties for bulk materials. The potential of nano in composites can already be seen in products that are on the market today like glass-fibre reinforced polymers and wood plastic (a mix of wood fibres and a polymer matrix). Case 1.3 and 1.4 shows how fibreglass-reinforced plastics is used in profiles to construct long free hanging building solutions that other materials like steel would not be able to construct. The composite, though not nano yet, has in these cases a better weight/strength relation, which thus makes it possible to construct long free hanging solutions.

Composite materials are as old as house building; since man started to mix sticks of wood in their clay houses man has explored the possibilities of strengthening the constructions. Today the most common is a mix of fibres and a matrix while research based on nano science looks on mixing nanoparticles, nanofibres, nanotubes or nanoclay and a matrix. Interesting, the rules of mechanics are in some sense the same for the old clay houses as they are for modern materials such as fibreglass-reinforced plastics and wood plastic.

Nano technology has improved strength, stiffness, toughness and thermal stability, through adding and structuring nanofibres, nanotubes and nanoclay. Nanoparticles has not given such good results, since a form with a length is able to distribute the forces that that hold the material to the matrix. There are three interrelated factors that can affect the strength of a material with the help of nanotechnology: the fineness of the fibres, clay or tubes, the surface/volume relation and the surface of the fibres, clays and tubes. The focus is on the relation between the material and the matrix and thus produces composites with better and more specific features.

The possibility of making stronger and tougher composites opens up many opportunities for architecture and construction. Composites can be made transparent, they have good insulation capacity and the weight/strength relation is better. Also from an industrialization perspective composites have advantages, since it is easier to make prefabricated parts in composite materials and depending on the direction and pattern of the fibres different features can be created.

Case 1.6: engineering properties of structural wood

Title	Climatic and long term effect on the molecular structure of wood fibres affecting the engineering properties of structural wood	
Date and version	October 31, 2006	Version A
Type of project	PhD and Post Doc	
Objective	To provide Improved models for service life models for wood frame structures (design and re-evaluation of structures) Basis for performance based design of wood structures	
Scientific need – link to goals of NanoByg	The project is linked to the NanoByg objectives: Safety and reliability Sustainability Serviceability incl. aesthetics	
Background		
Scope of work / methodology		
Interface	Links to other NanoByg projects x Other links x	
Participants	Name and contributions See scope of work	
Start and duration		
Costs		
Deliverables	Improved models for service life models for wood frame structures (design and re-evaluation of structures) Basis for performance based design of wood structures	
Proposers	Staffan Svensson, Lisbeth Thygesen, Preben Hoffmeyer, BYG•DTU	
Contact person	Staffan Svensson, Associate Professor Department of Civil Engineering, Technical University of Denmark Brovej, Building 118 DK-2800 Kgs. Lyngby, Denmark Phone: +45 45 25 17 48 e-mail: nss@byg.dtu.dk	

Case 1.7: alternative fly ashes for cement based materials

Title	Evaluation of alternative fly ashes for cement based materials	
Date and version	October 31, 2006	Version A
Type of project	PhD and Post Doc	
Objective	To investigate the possibilities for fly ashes otherwise identified as waste fractions to be used for cement based materials as a substitute for coal fly ash in an environmental sustainable way. To upgrade fly ashes by electrochemical pre-treatment	
Scientific need – link to goals of NanoByg	The project is linked to the NanoByg objectives: Safety and reliability Sustainability Serviceability incl. Aesthetics	
Background		
Scope of work / methodology		
Interface	*Links to other NanoByg projects* *x* *Other links* *x*	
Participants	*Name and contributions* *See scope of work*	
Start and duration		
Costs		
Deliverables	Identification of suitable fly ashes to be used with or without electrochemical pre-treatment. Selection based on both cement properties and environmental issues. Waste reduction by reuse of fly ash otherwise disposed by landfilling.	
Proposers	Lisbeth M. Ottosen, Iben V. Christensen, BYG•DTU	
Contact person	Iben V. Christensen, Assistant Professor Department of Civil Engineering, Technical University of Denmark Brovej, Building 118 DK-2800 Kgs. Lyngby, Denmark Phone: +45 45 25 17 48 e-mail: ic@byg.dtu.dk	

Case 1.8: Electrochemical removal of chloride from concrete

Title	Electrochemical removal of chloride from concrete with focus on changes in porosity, pore structure etc.	
Date and version	October 31, 2006	Version A
Type of project	PhD and Post Doc	
Objective	To investigate changes in concrete quality as a result of electrochemical chloride removal. To evaluate if electrochemical removal of chloride is recommendable.	
Scientific need – link to goals of NanoByg	The project is linked to the NanoByg objectives: Safety and reliability Sustainability Serviceability incl. Aesthetics	
Background		
Scope of work / methodology		
Interface	*Links to other NanoByg projects* *x* *Other links* *x*	
Participants	*Name and contributions* *See scope of work*	
Start and duration		
Costs		
Deliverables	A possible alternative to presently used methods for chloride removal	
Proposers	Lisbeth M. Ottosen, Iben V. Christensen, BYG•DTU	
Contact person	Iben V. Christensen, Assistant Professor Department of Civil Engineering, Technical University of Denmark Brovej, Building 118 DK-2800 Kgs. Lyngby, Denmark Phone: +45 45 25 17 48 e-mail: ic@byg.dtu.dk	

Case 1.9: Cement

Björn Johannesson, DTU

Lyngby, Denmark 2006 10 30

Hysteresis in the sorption isotherm:

Depending on the direction of moisture accumulation, i.e. moisture uptake or loss of moisture from sample the results becomes significant different. This is believed to a consequence of the so called ink bottle effect at the microscopic level of the pore system (in the range of about 1-100nm). The phenomena of hysteresis is almost always observed in measurements but is very seldom implemented in moisture transport models. This is a crucial drawback in classical moisture fixation and transport models. A relevant project is measurements on hysteresis together with theoretical works leading to improved numerical models for moisture transport in building materials.

Solid solution reactions in the C-S-H gel:

It is a well known fact that standard solubility calculations based on basic thermodynamic considerations do not reflect the behavior of the C-S-H gel in cement. This solid constituent is the single most important component of cement. The knowledge about the true thermodynamically equilibrium is very important since it governs the key to the mechanism behind degradation of the material. By using extended theories, that is, the solid solution method, it is possible to significantly improve the model. Experimental and theoretical work has been done in this field of research, however many issues such as the influence of activity remains an unknown factor. The processes is important for the understanding of degradation of cement based model and its underlying mechanism is to be find by analyzing properties at the micro-scale of the highly amorphous C-S-H. The size of components of the C-S-H is typically a few nano-meters.

Diffusion of ionic species in cement based materials:

In most models for concrete durability dealing with multi-ionic diffusion in the pore system electrolyte treat all different diffusion resistances a scaled value of the known diffusion constant in bulk water. Measurements using steady state diffusion cells, however, reveals that positively charged ions in many cases diffuses much slower than negatively charged ions. Hence for these cases a single scaling factor modeling the pore system tortuosity is not relevant. Some measurements suggests that it is only the pore systems having a significant part of its total porosity assigned pore sizes in the range of 0 – 40 nm which gives results with heavily reduced diffusion of positively charged ions. Probably it is the electrical forces and interactions of ions and solid surfaces at micro-scale which governs this behavior. A relevant nano project would be to analyze the described process in more detail.

Case examples: iNANO/Portland cement and Fiberline

articles: XXX

2 Functional surfaces

Funktionelle overflader i nanoskala-applikationer i byggeriet

af Marianne Strange, seniorrådgiver, Dansk Polymerer Center, Forskningscenter Risø

Pga. den hastige udvikling inden for bl.a. nanoteknologien findes der i dag en lang række teknologier der kan anvendes til fremstilling af nye skræddersyede overflader med indbyggede specifikke eller intelligente funktioner. Materialets yderste nanometre kan altså skræddersyes, enten ved en kemisk eller en fysisk modificering, til for eksempel at være smudsafvisende eller antifoulende, selvrensende, slidbestandige, korrosionsbestandige osv. og er en derfor et vigtigt område indenfor byggebranchen- både af hensyn til det æstetiske udtryk, men også rent holdbarhedsmæssigt. Nedenfor er angivet teknologier og applikationsområder der enten allerede er tilgængelige eller som snarest forventes at kunne få en vigtig betydning i byggeriet.

Applikation	**Fremstillingsteknologi**
Antifouling overflader	Kemisk overflademodifikation vha. plasmabehandling hvor overflader modificeres med molekyler der forhindrer organisk materiale (alger, bakterier) i at vokse på overflader.
Anti-graffiti overflader	Ved at behandle overflader med en tynd sol-gel film er det muligt at fremstille smudsafvisende keramiklignende overflader.
Selvrensende overflader	Overfladecoatninger med eller inkorporering af nanopartikler der virker aktivt mod snavs og bakterier. Et eksempel på dette er fotokatalytiske overflader der ved interaktion med uv-lys kan nedbryde organisk materiale.
Intelligente vinduer	Overflademodificering af glas med selvregulerende solafskærmning f.eks. i form af en tynd polymerfilm eller flydende krystaller.
Energiproducerende bygningselementer	Integrering af tynde solcellefilm i bygningselementer der herved kan producere energi.
Maling eller lak med særlige dekorative over-flader	Formulering af maling eller lak med nanopartikler der kan give specielle optiske effekter .
Selvreparerende overflader	Overflader der kan reparere sig selv i forbindelse med skader eller nedbrydning.
Integrerede/Indbyggede sensorer	Overflader der udsender et signal ved en ændring i det omkringliggende miljø, eksempelvis termofølere eller forureningsindikatorer

Brandhæmmende overflader	Coatning en række forskellige overflader med et tyndt lag af et brandhæmmende materiale

Tomas Zwieg TI

Peter Kingshott iNANO

One major problem with building is the inner climate. The trade-off is to use materials that do not seal of the climate, though at the same time it should not waste heat energy. The solution so far has been ventilation, but the amount of heat that sips out of a building in this way has been far too high. Functional surfaces, offers a better solution to this problem. Photo catalytic substances, placed in building materials, that can clean the air and surfaces that can deposit fine and ultra fine particles help to keep a healthy inner climate with out emitting large amounts of heat.

Per Møller er skeptisk før photokatalyse

isphobic, så at det ikke kommer is på

Case 2.1: New air-cleaning building materials leading to more healthy and energy efficient buildings

Henrik N. Knudsen, Department of Health and Comfort,

Danish Building Research Institute, Aalborg University

Pawel Wargocki, International Centre for Indoor Environment and Energy, Department of Mechanical Engineering, Technical University of Denmark

Background

So far building materials have been considered sources of indoor air pollution with potentially negative effects on the health, comfort and productivity/learning of building occupants. Consequently, the trend has been to reduce emissions from building materials, which at the same time reduce the energy demand for ventilation of buildings, which in turn is required to remove/dilute indoor pollutants. With new nanotechnologies there is a potential to develop innovative indoor materials that can clean the air from unwanted pollutants, apart from their normal functionality.

Innovation/new possibilities

Recently new building materials were introduced on the market. These materials are produced based on nanotechnology, which makes it possible to design a material surface with different nanocrystals that have various new properties. These properties include the possibility of cleaning the air of odorous substances and other pollutants that can have negative effects on the health, comfort and productivity/learning of building occupants. The materials include those that have large surfaces such as paints and plaster, carpets and curtains. The air cleaning is based either on active or passive processes. The active process is photo catalytic oxidation by UV light transforming unwanted chemical substances into “innocent” compounds. The passive process is based on the adsorption of pollutants onto the surface of materials or absorption of these pollutants into the structure of the materials. Other air cleaning technologies can also be considered. The new process of air cleaning does not require extra energy like ventilation or traditional filter systems. This can reduce energy demand for ventilation of buildings, which in Europe accounts for about 35% of all energy consumed.

Objectives

The aim of the project is to study the potential of new materials based on nanotechnology to clean the air, in terms of their impact on the health, comfort and productivity/learning of building occupants and the benefits for energy required for ventilation of buildings.

Experimental method

The impact of new air-cleaning building materials will first be tested in small-scale experimental chambers and full-scale test rooms by comparing ventilation required to obtain a certain level of air quality compared with traditional building materials. The air quality will be assessed by applying sensory methods (comfort) measuring perceived air quality and in chemical terms by measuring the concentration of chemical compounds. If these tests confirm the positive impact of the new materials

on air quality, the materials will be used in real buildings where their impact in relation to energy demand for ventilation as well as the health, comfort and productivity/learning of people staying indoors will be evaluated.

Possible applications and perspectives for the construction sector and society

The new knowledge generated in the project will contribute to a clarification of the extent to which air-cleaning materials can improve the indoor air quality and reduce ventilation requirements. Thereby, it contributes to an accommodation of the requirement in the EU Directive 2002/91/EF (Energy Performance of Buildings) that energy consumption in buildings should be reduced without compromising the indoor environment. It is also relevant for the compliance with requirements in the Danish Building Regulations and the Parliamentary decision from June 2005 about further reduction in the overall energy consumption of 25 % by 2010 and 25 % by 2015. The results of the project will create focus on the importance of developing new air-cleaning materials that improve the indoor air quality, reduce ventilation requirements and consequently energy consumption. This will add to the incentive among manufacturers of building materials to develop more indoor climate friendly materials. The project will strengthen the importance of labelling schemes for pollution from materials and furnishing. Finally the results could become a part of future guidelines and standards for ventilation requirements for buildings.

If successful, the project will completely change the way we think about building materials. From being a simple shell that protects us from the cold outdoor environment, it can turn into an active part ensuring a healthy indoor environment. This requires new thinking in the building sector to develop innovative and better building materials that ensure a healthy indoor environment, higher energy efficiency and protection of the environment.

Target group:

Energy authorities, authorities responsible for ventilation standards and guidelines, building regulations and labelling schemes for emissions from building materials.

Possible actors:

Indoor climate scientists, companies producing air-cleaning materials/products, building owners, etc..

Case 2.2: Effect of active surfaces in buildings on particle deposition

Proposed by:

Alireza Afshari, Department of Health and Comfort,

Danish Building Research Institute, Aalborg University

Innovation/new possibilities

In recent years, exposure to fine and ultrafine airborne particles has been identified as an important factor affecting human health. Several researchers hypothesise that an increased mortality rate is associated with the particle levels prevailing in urban air. The awareness of the impact of airborne particles, particularly fine and ultrafine particles, on health is growing. Ultrafine particles can penetrate deeper into the respiratory system and can deposit there with a higher probability than larger particles due to their larger diffusion coefficient.

The control and treatment of the particles generally falls into three main categories: source control, ventilation control, and removal control. Source control should always be the first strategy examined. When source control is not feasible or practical, ventilation control should be the next option. But in many of our urban environments today, the outside air does not meet the required criteria with regards to particles contaminants. Therefore, when it is clear that neither of the two first control strategies mentioned above would reduce the level of contaminants in the affected space, removal control should be employed.

One approach to improve indoor air quality is the use of active surfaces in buildings which may increase deposition of ultra fine particles onto the surfaces. There are several experimental studies for particle deposition indoors for non-industrial environments. They found that there were observable differences in the rate loss coefficient between the smooth and the rough surfaces. The deposition of particles onto surfaces is a positive phenomenon from the perspective of human health and material damage.

Case 2.3: Grundfos Case Mirco sensors with nano coating

Grundfos recently produced the first chip for micro sensors in the production facilities for semiconductors set up at Farum (Copenhagen) one and a half year ago as the first production facilities for semiconductors in Denmark. The facilities were established after several years of research conducted by Grundfos in co-operation with the Micro Electronics Centre of the Technical University of Denmark.

The semiconductor chip is made from silicon wafers, and a special nano coating, developed as a Ph.D. project and subsequently patented by Grundfos, makes the chip resistant to water and other liquids.

Unlike traditional pressure sensors the Grundfos micro sensor is so tiny that, in principle, it can be integrated in even the smallest pumps. In the short term the production of micro sensors is aimed at use in Grundfos' own products, but in the long term micro sensors will also be relevant in other products as it is suitable for measuring pressure, flow and temperature in liquids in general.

Grundfos started the production of microchips with 10 employees in September 2001, and today there is a staff of 24 employees at the Farum facilities. Microchip production does not require large resources of raw materials, but on the other hand it requires well educated staff and big investments in production equipment. This means that this kind of production is very suitable for Denmark, and Grundfos regards this field as a strategically important basis suitable for integration in the pump company. Whereas the microchips are produced in Clean Room facilities at Farum, the pressure sensors in which the chips are integrated are produced in Grundfos Electronics at Grundfos HQ in Bjerringbro in the western part of Denmark.

The first silicon wafer with microchips was sent to Bjerringbro in early March this year, and mass production of pressure sensors will start towards the end of the year. In the beginning Grundfos expects annual production to amount to some 2m pressure sensors.

Grundfos has spent some 1.9 billion DKK on research and development in the past five years. The investments at Farum amount to a little over 100m DKK.

Case 2.4: BASF - a new generation of binders for paints and coatings

BASF is presenting its new generation of binders for architectural coatings at this year's European Coatings Show (April 26 - 28). COL.9® is a high-tech product combining inorganic and organic chemistry. BASF researchers already won the 2004 Coatings Award (Farbe-und-Lack-Preis) for developing this innovation, and COL.9® DS 1000 has now become the first commercially available product in this specialty segment for outdoor applications. In the new COL.9® binders, inorganic nanoparticles are homogeneously incorporated into organic polymer particles of water-based dispersions. The resulting nanocomposite dispersions combine the benefits of inorganic binders – such as hardness and permeability – with those of organic binders – such as elasticity and water resistance.

COL.9® DS 1000 was developed specially for façade coatings. After application and drying, the inorganic nanoparticles form a homogeneous three-dimensional network structure covering the entire coating film. Because of this extremely fine nanostructure, facade coatings based on this innovative technology are extremely resistant to dirt and chalking (separation of white pigments), do not crack, and display high color tone stability. The lattice structure composed of inorganic and organic components is furthermore responsible for its excellent fire behavior properties. The color film does not melt in the presence of fire and does not drip.

"Our new generation of binders creates the basis for new, significantly better performing facade coatings," says Ralph Schweens, head of BASF's Business Unit Adhesives and Construction Industry Europe. "It makes exterior paint jobs better able to withstand tough weather conditions. Not having to repaint so often is a hands-on benefit for the consumer – especially since the facade keeps that freshly painted look for longer". It's also why BASF chose to market the new binders using the slogan Anti-aging for facades.

As a leading supplier of products for the construction industry, BASF develops, produces and markets polymer dispersions worldwide. They are used for the production of textured finishes, finishing systems and compounds, advanced super plasticizer, roof coatings or ceramic tile adhesives for example. In paints and architectural coatings they are used as binders. BASF’s strengths include its efficient research and development and global application technology. The business is part of the Functional Polymers division within BASF’s performance products segment.

Case 2.5: Rambøll Effect of surface treatments on natural stone and concrete

At Ramboll, we are a large group of senior engineers and technicians that are often involved with the complex problems regarding surface properties of concrete and natural stone. We daily work with life-time estimations of bridges, tunnels and other buildings, and in that context we carry out detailed durability assessments of many kinds of structures, including different building materials.

We are currently involved with several research and development projects dealing with the durability and maintenance of natural stone and concrete, and we often function as advisory consultants for building owners, entrepreneurs and architects in these aspects. Through these activities we definitely experience the need for development and implementation of surface treatments that facilitate cleaning without affecting the aesthetic appearance or decreasing the durability of the stone or concrete. We also consider the development and implementation of treatment types that will prolong the lifetime of these building materials, a high priority.

Ramboll are very interested in participating in the NanoByg, with a project that will help the safe use of surface treatments on natural stone, concrete and/or bricks. We suggest the NanoByg to develop guidelines and specifications for the performance of surface treated building materials.

Presentation of the innovation/idea (or technology/scientific area)

Different kinds of surface treatments are on the market today to facilitate cleaning & maintenance, removal of graffiti, to prolong the lifetime of constructions and for other applications as well. The concern here is the safe use of these surface treatments on concrete, natural stone and bricks. In the building industry there is a great lack of guidelines on what type of treatment is appropriate for the different applications in various environments. Many treatments do therefore not work as it was originally intended or it has unforeseen side effects such as decreased durability of the substrate, increased decay rates, moisture problems, discolorations, colour changes etc.

Many of the treatment products and its intended interactions with moisture or dirt are considered nanotechnology. However, eventual unintended side effects such as degradation of the building material because of altered surface properties, is a process that also takes place at the nano-scale. Such effects are very important points to consider before applying any kind of surface treatment, and it calls for a very specialised knowledge of the surface treatment itself, the substrate and the environment/actions taking place on both sides of the treatment.

To avoid/minimise these negative effects we propose that a project in the NanoByg work out detailed guidelines, standard specifications and standard tests on the applicability of the various treatments set in context to the actual building material. These guidelines should specify the minimum requirements on the performance of the treated building material for a specific application. The different important performance parameters should be determined through various standard tests, and criteria for its safe use should be outlined. Performance parameters for the treated stone products could be:

1. Freeze thaw resistance in presence of water
2. Resistance to salt exposure
3. Thermal stability
4. Colour stability (treated surface vs. untreated)
5. Vapour permeability
6. Discolorations

What are the possible applications, impacts and perspectives for the construction sector and society?

Treatment products for stone and concrete are on the market today, but the knowledge of the various products are sparse in the building industry. The suggested guidelines and test programme would benefit the building industry. First of all, it will minimise costly restorations from bad use of surface treatments. Secondly it will promote the use of surface treatments. Here at Ramboll we see the lack of standards and guidelines for safe use on surface treatments as an important barrier for the use of nano-technological surface treatments. The various building partners often has doubts on the effectiveness and durability of surface treatments, but also in respect with its interactions with the substrate and the environment. Through strict and safe guidelines, the various partners will be more compelled to choose a treatment. Guidelines and specifications will this way enhance and promote the use of Nano-technology in the building environment.

Case 2.6: Nanon, Softplasma™

How does it work?

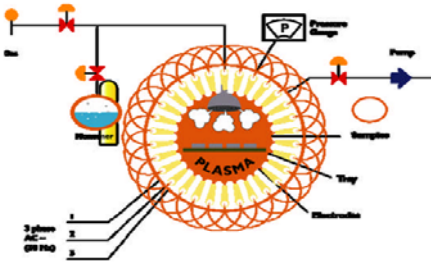
The Softplasma™ process is conducted under very low pressure in vacuum into which a gas is injected The gas is ionized in a low-energy plasma field to clean and activate the substrate surface. Then, special monomers are introduced in the chamber and polymerised on the substrate.

A permanent coating of 10-100 nanometres is then created and chemically bonded to the substrate. A the same time, the fundamental, known physical properties of the basic material are maintained.

1 Large range of substrates

2 Creation of a permanent coating with Softplasma™

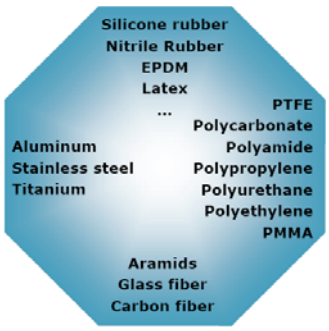
3 painting, gluing, over-molding... strong bonding to a second substrate



Softplasma™, low-energy plasma polymerization technology in vacuum

Large range of difficult substrates

Softplasma™ can be applied on different elastomers, plastics and metals:



Low production Cost

Softplasma™ is a batch process (Roll-to-roll, tumbler,...). The production can be done in Nanon or in your premises.

Please contact us for further information on our Softplasma™ process.

Nanon A/S, Priorparken 878, DK - 2605 BRØNDBY
PHONE +45 43 48 35 01 – FAX +45 43 48 27 91 – SITE www.nanon.dk – Email sales@nanon.dk

Case 2.7: Dansk Tagteknik A/S

Dansk Tagteknik A/S er et nystartet mindre firma, der har specialiseret sig i afrensning af belægningsten og murværk. Der satses på at anvende coating baseret på nanoteknologi. Man har kontakt til danske distributører, men har især direkte kontakt til tyske firmaer, som man har besøgt.

Man ser store muligheder – allerede indenfor 1 til 2 år. Særlig i forhold til algevækst på fliser og murværk er der et stort potentielt marked indenfor byggesektoren. Man følger udviklingen tæt – og overvejer at være med til opstart af en virksomhed, der skal specialisere sig i at levere nanoprodukter til byggeriet. Nano-coatede produkter afviser snavs og begroning, og får produkterne til at se nye ud i længere tid.

Barriere

Der er meget begrænset viden om nanoteknolgi. Folk er ofte bekymrede mht evt. bivirkninger som nanopartikler måtte kunne give anledning til.

Nano-coating produkterne er for dyre i øjeblikket herhjemme. De er billigere i Tyskland.

Nano-byg

Der er stort behov for en aktivitet som nano-byg, fordi der er brug for mere information om nanotknologiens muligheder.

Dansk tagteknik vil meget gerne deltage i et netværk omkring Nano-byg.

3 Optics

Case 3.1: LED Sensorstyret intelligent LED belysning i byggeri

Carsten Dam-Hansen, seniorforsker,

Afd. for Optik og Plasmaforskning, Forskningscenter Risø

Forskningen1 har vist, at dagslys er den form for lys, som mennesker befinder sig og arbejder bedst i, og at vi foretrækker dagslys frem for kunstlys. Dagslys varierer i modsætning til kunstlys i både styrke og farve i løbet af dagen, hvilket ikke har kunnet efterlignes med traditionelle kunstlyskilder. Nye lyskilder2 baseret på lysdioder giver netop en mulighed for at styre lysets styrke og farvesammensætning.

Ideen i dette projekt er derfor at udvikle et system til intelligent belysning i bygninger baseret på nye lysdiode lyskilder som kan supplere og følge dagslysets rytme og dermed bringe dagslyset ind i bygningen. Systemet skal skabe øget velvære og effektivitet hos de mennesker, der opholder sig og arbejder i bygningen og systemet vil samtidig være energibesparende. Belysningen skal være af høj kvalitet og systemet skal regulere belysningens styrke og farvesammensætning efter arbejdssituation, individuelle ønsker samt de aktuelle omgivelsesforhold, dagslyset.

Lysdioder eller LEDs (Light Emitting Diodes) betegnes som fremtidens lyskilde pga. deres høje energieffektivitet, lange levetid og robusthed sammenlignet med f.eks. glødepærer. Den globale nanoteknologiske forskning og udvikling leder imod LED enheder med stadig større lysstrøm og stadig højere energieffektivitet. I dag er vi nået til et stadie hvor LED er begyndt at være egnede til generelle belysnings anvendelser.

I Danmark har vi igennem to forskningsprojekter[2] vist, at det er muligt at udvikle LED lyskilder/lamper med stor lysstrøm, som har en energieffektivitet der er 3-5 gange højere end for glødepærer. Forskningscenter Risø har vist at det er muligt at specialdesigne og styre lysets egenskaber, som farvetemperatur og farvegengivelse, til specifikke anvendelser.

Muligheden for at styre og specialdesigne lyset gør disse LED lamper enestående til et intelligent belysnings system. Sensorinformationen om omgivelserne (dagslyset) skal komme fra nye optiske sensorer, der udover at måle lysniveauet i omgivelserne også skal kunne måle farvesammensætningen. Der findes i dag dyre måleinstrumenter som kan benyttes som sensorer i demonstrationssystemer, men til systemet skal udvikles nye optiske sensorer baseret på halvlederkomponenter og nanostrukturerede holografiske strukturer. Polymer replikering af disse strukturer

1 Se f.eks. rapport fra Lighting Research Center, Rensselaer Polytechnic Institute http://www.lrc.rpi.edu/programs/daylighting/pdf/DaylightBenefits.pdf

2 Risø har afsluttet PSO projekt nr. 336-54 Energibesparelser med diodelys medio 2005 og PSO projekt nr. 337-068 Udvikling af LED lyskilder og lamper løber frem til ultimo 2006.

skal muliggøre en billig massefremstilling af sensorerne. Vi har på Forskningscenter Risø vist at dette er muligt igennem udvikling af en integreret sensor til en optisk mus.

Projektet vil tage udgangspunkt i en analyse og vurdering af ideens potentiale, teknologisk og markedsmæssigt. Et test system opbygges, som kan demonstrere systemets virkemåde og egenskaber i testlokaler. Herefter skal nye LED lamper og optiske sensorer designes og udvikles, og integreres i et intelligent belysningssystem.

4 Sensors and electronics

Case 4.1: Indlejrede trådløse sensorer i byggeriet

af Lars Lading, STC og Leif Højslet, Teknologisk Institut

I det foreslåede projekt udvikles trådløse sensorsystemer baseret på nano- og mikroteknologi med særlig henblik på fugtmåling i byggeriet.

Sensorer og aktuatorer er potentielle kommende nøglekomponenter i den fremtidige automatisering i overvågning af f.eks. bygningers strukturelle tilstand. Man kan sige at sensorerne overvåger og monitorer, mens aktuatorerne reagerer og kompenserer for evt. problemer i bygningsværket, f.eks. ved fugt.

Sensorer er normalt konstrueret og fremstillet som selvstændige komponenter forbundet med kabler. Kravene om stadig bedre *performance* og billigere sensorer er imidlertid oftest uforeneligt med sensorer som selvstændige komponenter med ledningsforbindelse. Derfor forventes sensorer i stigende omfang at blive indlejrede i konstruktioner og ofte med trådløs forbindelse.

Trådløse sensorsystemer bliver med stor sandsynlighed et af de helt store vækstområder, som vil følge efter udviklingen af mobiltelefoni. Der er betydelige internationale aktiviteter på området.[3] I Danmark beskrives udviklingen af sensorer og aktuatorer som lovende og der er en forventning om at danske firmaer kan få stærke niche positioner indenfor sensorer og aktuatorer.[4]

En nødvendig forudsætning for denne udvikling er, at der findes sensorer, som er kompatible med de trådløse netværk. Sensorer, der kræver en lokal energiforsyning, anvendes allerede i et betydeligt omfang og mange teknologier er udviklet. En væsentlig udfordring her er energiforsyningen: batterier udgør en betydelig omkostning; de har en begrænset levetid og er miljømæssigt problematiske. Tilslutning til et trådet el-net eller anden energiforsyning begrænser anvendelserne meget. Trådløse sensorer tillader monitorering i ellers ikke tilgængelige miljøer, fx kemiske og/eller fysisk isolerede omgivelser. For RFID[5] teknologien (den forventede erstatning for *bar-code*) er det helt afgørende, at batterier ikke skal indlejres i RFID chippen. Dette vil også være afgørende for mange fordelte sensorsystemer. Trådløse systemer, der indgår i strukturer, hvor der dels er ledende elementer (fx armeringsjern), dels refleksion og afbøjning af stråleudbredelse, kan være meget upålidelige. Det er væsentligt, at der etableres en dynamisk arbejdsdeling mellem de enkelte elementer i netværket for at opnå en tilstrækkelig sikkerhed i informationsoverførslen. På et højere niveau vil det ofte kræve, at den trådløse kommunikation følger internationale standarder, fx *ZigBee og Bluetooth* specielt for sensorer.

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3 Et indtryk kan fås på: Second Wireless Sensor Confernce, San Diego June 2005.

4 ATV møde d. 24. november 2004, "Sensorer og aktuatorer: Et fortsat dansk vækstområde? - om betydningen af højteknologiske komponenter i industrielle produkter og processer", ATV.

5 RFID: Radio Frequency IDentificatoin

Bygninger repareres/vedligeholdes årligt for flere milliarder kroner. Det foregår i dag typisk ud fra en visuel inspektion eller ved måling af makroskopiske procestilstande af udvalgte bygningsdele, hvoraf fugtindholdet er en vigtig parameter. Den nuværende fremgangsmåde er ikke altid hensigtsmæssig. Fejl/skader opdages nogen gange ikke i tide – til tider med katastrofale konsekvenser. Der foretages unødvendige udskiftninger og reparationer, som måske i sig selv kan fremprovokere skader. Desuden har styring/kontrol af fugtindholdet fundamental betydning under fremstilling og færdiggørelse af nye bygninger og konstruktionsdele. Fugtindholdet er en vigtig styrende parameter med hensyn til efterbearbejdning, udlægning/påsætning af gulvbelægninger, overfladebehandlinger og opsætning af vægbeklædning. Forkert timing kan have store konsekvenser for etableringsøkonomien, efterfølgende skadesoprettelse eller indeklimaet. Med nuværende teknologi er løbende detaljeret fugtmåling tidskrævende og teknologisk kompliceret, hvis den ønskede høje dataopløsning skal opnås. Derfor er det yderst sjældent, at den reelt nødvendige detaljerede fugtmåling udføres i tilstrækkeligt omfang med dagens teknologi. Udvikling af en prisbillig, trådløs sensor, der kan fungere i det barske miljø i en bygningskonstruktion, vil resultere i en betragtelig produktivitetsforbedring, som der efterspørges i byggeriet.

Udvikling af billige trådløse, let implementerbare fugtsensorer baseret på mikro- og nano-teknologi, vil have revolutionerende betydning for byggeriet under alle dets faser og senere under drift og vedligehold. På sigt kunne denne type sensorer inkorporeres i det "intelligente" byggeri, som selv overvåger og styrer driftmæssige parametre med henblik på forebyggelse af f.eks. fugtskader.6 Sensorer og aktuatorer vil kunne udnyttes til kontrol af den generelle strukturelle integritet i store konstruktioner som bygninger, broer og vindmøller. Et eksempel på hvorledes teknologien kan udnyttes i byggeriet er små passive sensorer i beton, som så kan aflæses trådløst for at undersøge og overvåge for revner i betonen. Et andet eksempel på et byggeri, hvor denne teknologi vil være efterspurgt, er den kommende Femern Bælt-forbindelse, hvor krav til holdbarhed og ydeevne vil være øget dramatisk i forhold til tidligere brobyggerier.

Indlejring af sensorer under ekstreme forhold med hensyn til plads, mekanisk belastning, temperatur, tryk og kemisk påvirkning repræsenterer en væsentlig udfordring både i relation til materialer og sensor design.

Centrale aktører i dette sub-projekt:

- Sensor Technology Center A/S
- Teknologisk Institut

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6 En gennemgang af byggebranchens behov og eksisterende teknologier er givet er publiceret af Lunds Universitet: Anders Sjöberg, LTH, Jakob Blomgren, IMEGO och Fredrik Hjortbäck, IMEGO: "En studie av byggbranschens framtida fuktmätningsbehov" January 2005.

Et eksempel på en enksperimentel demonstration i beton er beskrevet i: Voutilainen et al. , "Novel Measurement Method of Humidity within Construction Structures", Helsinki University of Technology Applied Electronics Laboratory, Series E: Electronics Publications E2, Espoo, Finland, 2002.

- Polymerafdelingen, Risø

Morten Bøgedahl, skall snacke med Eric

???

5 Integrated Energy production and distribution

Case 5.1: Plastic Solar Cells

Solar cell is on of the energy harvesting technology that has the greatest potential in relation to sustainability in particular and eco-efficiency in general. However, the most used material – silicon – requires an expensive and energy consuming production method, some of the models have even been accused of having a negative life cycle energy balance. Strategies to innovate in solar energy should thus rather be directed at industrialization, to bring down the cost and energy consuming production methods of silicon.

Here, thin film solar cells have shown a promising development, they are easy to produce, it is a highly flexible material, and thus they are easy to distribute and work with. This technique produces solar cells by printing a thin layer of semiconductor on a metal foil, which then can be distributed on roles. The downside of these techniques is that the use chemicals that are highly damaging to the environment, for example cadmium telluride and copper indium diselenide. Organic or plastic solar cells though have a solution to both these problems, they are as easy to produce as the thin film solar cells and they do not have any polluting waste in them.

The production method of a plastic solar cell is very different from that of a silicon based cell. A polymer solution is mixed and can be printed or spread of over a surface, which thus makes industrial production highly cost efficient. This is a binary blend, thus containing both the anode and cathode of the electrolytic process, which thus makes the production comparatively easy. Off course, also the plastic solar cells have their problems; the longevity and energy efficiency is much lower than the silicon solar cells. However, the opportunities that nano technology has brought with them have created better ways of analysing and structuring plastic. Nano technology has mostly illuminated the importance of having as much contact surface between the different component of the photovoltaic reaction (or process). The research today is focused on getting higher efficiency through experimenting with nanoparticles, nanorods or simply a zig-zag muster that combines the different layers of the photovoltaic reaction. At Risø the research team is not only focused on efficiency, but also on longevity and processabilty, which are of high importance to make it attractable for industrial production.

A picture of the first 0.1 square metre plastic solar cell made by screen printing at Risø on the 01. December 2004.

Although plastic solar cells today have a relatively short life expectancy and low efficiency the price is very advantageous. Traditional silicon based solar cells cost approximately 5000 DKK per m2 while a plastic solar cell will cost less than 100 DKK per m2. Further, because of the environmental harmless content of a plastic solar cell, there is no danger in throwing them out after a short period of usage.

Plastic solar cells have many advantages that give them inexhaustible application opportunities. They are flexible and thin enough to be used as clothing, on the page of a magazine or book and harm the environment less then a piece of paper. In this way you could charge your mobile phone while strolling around a park on a sunny day, by wearing your newly bought jacket made out of plastic solar cells. The easiness to handle combined with the environmental friendly waste of plastic solar

cells also makes it possible to use exchangeable lamina of plastic. After a couple of years when the solar cell has degraded you could take the old lamina and exchange it for a new fresh one (then even more efficient). The old one can then just be disposed through the normal garbage maintenance.

Case 5.2: “Picking” CO2 to create energy

One of the major problems of the use of solar energy in houses is the storage of energy. During the day when the sun is shining the solar cell produces lots of energy, while when the sun sets and we put on the electric light the solar cell doesn’t produce any energy. Traditionally this problem has been solved with batteries, but they are inefficient in transforming energy and highly environmental unfriendly.

As a new track within solar cell research a group of researchers at Risø are now investigating the possibility to produce combustion fuel (formic acid or methanol) from carbon dioxide and light. It is today common knowledge to facilitate a catalytic system that can induce this chemical reaction on the nanoscale. And the beauty of this system is that the only thing you need is air and daylight, and even better in today’s context, it is carbon dioxide neutral, thus a highly sustainable way of binding energy. The major challenge of this research project is to “pick” the CO2 out of the air. This is what makes it unique and possibly prosperous. Even if the discussion on global warming has given a picture of high level of CO2 in the atmosphere, it is not enough to use air in its normal form. The techniques that exist today to extract CO2 from air are far too expensive and energy consuming to use in an integrated energy production. Nano technology has though given this field of research new opportunities and combined with solar energy solutions are within sight.

However, the story does not end here, if we now combine a fuel cell with this synthesis we have an integrated device to produce electricity. With these different technologies it is possible to create a device that is self sufficient, at least as long as we can breathe and see the sun. Applied to a house it will make all external sources of energy unnecessary. During daylight the device can produce enough formic acid for the house to manage the energy demand for the night.

It is today also possible to produce such small fuel cells that a device like this can be used for sensors or other small electric devices that are increasingly used in houses. The best known example is a fire alarm that most of us have in our house today. The device would then replace the battery making the fire alarm work for a life time.

We should find a Fuel cell case

6 Environmental control and impact

KU Susann Stipp Kontakt: Lektor Susan Stipp, tlf. 35 32 24 80 eller mobil 24 65 41 14.

Prof. Miljø Kemi Hans-Christian Bruun Hansen

Case 6.1: maxit airfresh® K mineralsk puds til indendørs brug

Nye vægge renser luften helt naturligt

Når du pudser eller maler med maxit airfresh®, får du renset luften både for generende lugte (røg, mados, indelukkethed osv.) og for skadelige stoffer som formaldehyd og ammoniak, der bl.a. findes i visse rengøringsmidler, træmøbler og tæpper. Den rensende effekt opnås ved hjælp af fotokatalyse – en naturlig proces, der aktiveres, når den behandlede væg udsættes for lys.

maxit airfresh® omdanner de generende lugte og skadelige stoffer til CO2 og almindelig vanddamp, der forsvinder af sig selv. Mængden af CO2 svarer til den luft, vi ånder ud, når vi trækker vejret, og mængden af vanddamp er så lille, at den nærmest ikke er mulig at registrere.

Teknologien er velkendt

Fotokatalyse handler dybest set om de reaktioner, der sker i de alleryderste molekylelag på en overflade. Man har ved at studere de fysisk-kemiske processer mellem atomer og molekyler på overfladen af titanoxid observeret, hvordan lysenergi skaber forskelle i molekylers og elektroners ladning og derved skaber forudsætningen for nedbrydning af organiske stoffer. Mere specifikt kan siges, at titanoxid reagerer med sollys eller kunstigt lys ved at opsuge energi fra lyset og katalysere oxideringen af organiske materialer og luftarter.

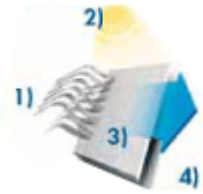
I Japan er man langt fremme med at udnytte denne proces ved at lægge et tyndt lag titanoxid i form af nanokrystaller ind i overfladen på f.eks. fliser, tapeter, puds, beton, glas, spejle osv. Da processen nedbryder organisk materiale, kan den bl.a. bruges til at fjerne luftforurening i form af organiske opløsningsmidler, ammoniak, nox'er etc.

maxit airfresh K er en mineralsk puds af høj kvalitet - fremstillet på basis af gips - til overfladebehandling af indvendige vægge og lofter i nyt og ældre byggeri.

Produktets enestående og særlige egenskab er, at det begrænser lugte og skadelige stoffer i luften indendørs ved fotokatalyse. Der opnås en væsentlig luftrensende virkning, og der sker en klar forbedring af indeklimaet. Forurening forårsaget af f.eks. nikotin optræder slet ikke eller næsten ikke på overflader pudset med maxit airfresh K. Nogle pletter på organisk basis, f.eks. kaffe, kan endda blive mindre ved brug af produktet. Fotokatalysens aktivitet vil altid være afhængig af det lys - dagslys eller kunstig belysning -, der er til stede. Meget lys betyder stor eller hurtig aktivitet, lidt lys betyder lav eller langsom aktivitet. Aktiviteten bliver bedre ved valg af f.eks. halogenlamper til rumbelysning. Produktet kan anvendes overalt i indendørs områder med undtagelse af vådrum. Produktet er dog egnet til køkkener og badeværelser i private husholdninger.

Produktbeskrivelse maxit airfresh K er en hvid, mineralsk puds med særlig virkning mod

skadelige stoffer i luften og lugte. For et varigt sundere indeklima.



Fotokatalyse-princippet

1) Lugte og skadelige stoffer i luften

2) Lys på væggen

3) maxit airfresh® væg

4) Renset luft

This maxit product is developed in Germany, however the R&D department in Denmark told us that they are on the way to establish nano competence, and with that connection to universities, also here in Denmark. Though not in the area of photo catalytic materials, but to better understand and improve the longevity, durability and wearing.

7 Overall nano-research and competencies

Case 7.1: Structure-property relationships of nano-structured materials

The nano to macroscale gap

Nanostructured materials often exhibit remarkable physical properties that may appear very attractive, but in practise may be difficult to realise in macroscopic materials, suitable for construction. Examples include properties such as thermal conductivity and water/humidity imbibition, which depends on the porosity of the material, i.e. size of pores, the "connectednes" (permeability) of pores and their amount by volume, relative to the material solids. Nano-scale porosity yields some exceptional properties (as exemplified by aerogels). Surface/interface properties (bonding, microbial inhibition, surface tension, friction) may likewise be tailored by nano-structural design.

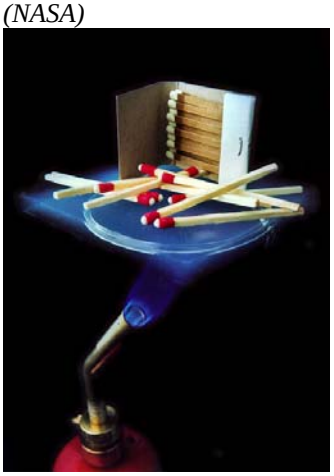
Bridging the gap

A 2.5 kg brick is supported on top of a piece of aerogel weighing only 2.38 grams (NASA)

At the Danish Polymer Centre, Risø, we routinely characterise macroscopic materials, structurally designed on the nano-scale. We do this by various X-ray scattering techniques that cover the range 1-1000 nm, otherwise only available at large-scale research facilities.

Inherently nano-structured materials are already in widespread use in construction. Concrete is one such example with a nano-scale porosity that is only indirectly controlled. Many thermal insulation products would benefit tremendously by reductions in pore size, i.e. designed for nano-scale porosity. In such cases, determining the relation between manufacturing and processing at the macroscopic level, with the nano-scale structure can open pathways to new high-performance materials for construction.

New designs, new opportunities



Extreme thermal insulation (NASA)

Improving physical properties by nano-scale design, make new possibilities available in architecture, by allowing thinner walls, larger windows, less heating installations etc.

Nano-structured materials can provide new functionalities and potentially significant energy savings.

8 Construction Sector

Case 8.1: Interview med entreprenører

Denne case bygger på interviews og mailkorrespondance med 3 danske entreprenørvirksomheder (NCC[7], CEG[8] og Pihl og Søn[9]). Virksomhederne er blevet adspurgt om deres syn på og viden om nanoteknologi, samt deres mulighed og incitament til at anvende nye materialer og teknologier.

Hvad er jeres opfattelse af nanoteknologiens muligheder?

CEG: Nye tiltag bruger ofte begreber som miljø og sikkerhed som løftestang/banebryder. Nanoteknologien åbner mulighed for at tænke mere "aggressivt" i løsninger og muligheder. Nanoteknologi vil helt sikkert blive en del af de danske håndværkeres hverdag... engang i fremtiden

Har I viden om nanoprodukter?

CEG: Kun lidt! Som firma er vi udførende og producerer med de værtøjer og materialer man kender idag. Når Nanoteknologien en dag bliver mere udbredt vil vi ganske naturligt få mere viden om den.

Pihl og Søn: Pihls kendskab går primært gennem materialerleverandørerne som leverer produkter der indeholder nanokomponenter. Det er et meget spændende område, som jeg tror vil få meget stor udbredelse i byggeindustrien. Både på materielsiden såvel på materialesiden

Hvad er entreprenørens rolle i forhold til materialevalg og introduktionen af nye materialer?

CEG: Ofte er materialer foreskrevet af arkitekter i samarbejde med bygherre. Andre og evt. nye produkter kommer som regel kun på tale hvis der følger en besparelse i kølvandet på dem.

Pihl og Søn: I langt de fleste tilfælde er materialerne defineret i designfasen, så i de fleste projekter er det ude af vores hænder. Men i de tilfælde hvor vi selv designer, har vi naturligvis mulighed for at påvirke beslutningsprocessen.

NCC: Når en entreprenør indgår i udviklingsarbejder med materialeproducenter tilfalder ejerforholdet materialeproducenten. Entreprenøren opnår således ikke en relativ konkurrencefordel fordi innovationen bliver tilgængelig for samtlige entreprenører i branchen. Det er således ikke dem som investerer, der får afkastet af innovationen. Et andet problem er byggeriets fragmenterede værdikæde, med skiftene samarbejdspartnere. Dette gør det vanskeligt at opbygge tryghed omkring samarbejdspartnerens kompetencer.

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7 Interview person: Lars Blåbjerg

8 Interview person: Arne Gotfredsen

9 Interview person: Rolf Carlsen

Der foretages Sjældent en samlet økonomisk helhedsvurdering af anlægspris/driftspris. Ofte fokuseres der alene på anlægsprisen fordi der er tale om

Case 8.2: Skiold

Background

Within the business of indoor mechanical farming equipment, some of the biggest challenges are hygiene and cleanability. SKIOLD foresees a range of opportunities to improve existing products by implementing new nano technology and new materials.

Feeding Troughs

One example is feeding troughs. Today, feeding troughs are manufactured in either stainless steel or polyester concrete. As an alternative to these well-known, but rather expensive materials , SKIOLD would like a material with the following characteristics:

- very smooth and cleanable surfaces
- the ability to lower or even eliminate bacteria growth
- Cost price lower than the cost of stainless steel
- A surface hard enough for the pigs not to damage it (biting, pushing)
- Suitable for injection moulding
- Must not damage the pigs or the pork when accidentally eaten

Today we experience problems with keeping the troughs clean, and this has a negative influence on the feed consumption of the pigs.

Old feed stuck in edges and corners of the trough is the perfect place for heavy bacteria growth, and these bacteria cause diseases, e.g. diarrea. This is very disturbing for the pigs, and causes the pigs not to gain weight, even though they keep eating.

Fig. 1: Existing troughs, polyester concrete and stainless steel

Pen separation

A widely used material for pen separation is PP, either as extruded rafters or as injection-moulded modules.

An alternative material to PP must

- have a hard surface
- be easy to clean
- be bacteria repellent
- have a low cost
- have the possibility of having water and feed tubes inserted or moulded in

Cleaning pig pens is very laborious, and the bacteria growth is enourmous. When measuring the weight gain of the first pack of pigs in new pens and comparing this to the weight gain of the following packs of pigs, the difference is quite a lot.

If this hygiene-effect could be re-established between each pack, the economic gain would be quite large for the farmers.

Fig. 2: Various pen separation solutions.

Peter Stouggard

Note: In the mail correspondence Peter Stouggard also mentioned cleaning of ventilation air from smell and nitrogen by nanotech catalysts as a possible area of application.

Case 8.3: Gurit – troublesome innovation structures

Jeg fik vist nævnt at jeg kommer fra et firma, der udvikler, producerer og sælger komposit materialer til vindenergi (vindmølleblade), marine (sejl- og motorbåde), fly (interiør), civil engineering (nye broer, nye arkitektoniske/kunstneriske one-off løsninger, reparation af gl. betonbroer), sport (ski).

Vi producerer råvarerne (epoxy, lim, epoxy prepreg, SPRINT, kernemateriale) samt køber og sælger de andre produkter, som vores kunder så køber af os for at kunne lave deres produkter. Vi laver ikke selv både eller vindmøllevinger, da vi så ville være i konkurrence med vore kunder.

Men jeg har, sammen med venlige og kreative arkitekter og andre byggefolk, brugt en del tid på at finde ud af hvilke produkter, vi ville kunne blive teknisk konkurrencedygtige med i komposit. Vi er kommet til den konklusion at der er et lille antal spændende produkter eller komponenter, hvor man med komposit vil kunne lave noget der vil være lettere at montere, mere spændende at se på rent og bo i, mere holdbart/billigere i verdligehold, men altså også dyrere end den eksisterende løsning, hvis man ikke regner de langtsigtede besparelser ind.

Fra marine området er vi vant til at direkte kunder og slutkunder ofte vælger at glemme de langtsigtede besparelser når de vurderer vores løsninger. Ofte bliver vi sammenlignet med vore konkurrenter pr. m2 eller kg, selvom det er "æbler og pærer" man sammenligner

Med risiko for at blive kritiseret for at være for kategorisk og firkantet, vil jeg karakterisere årsagerne til at der ikke findes flere nye byggematerialer og byggekomponenter (feks. Komposit) her:

1. Konservatisme hos dem der skal udvikle dem (os og vores kunder), da vi og de skal prioriterer de forretningsmuligheder, hvor der kan sælges eksisterende produkter, har lille indbygget erstatningsrisiko og hurtigt/kortsigtet afkast

2. Konservatisme hos dem der skal købe byggeriet, da de ikke ønsker at være de første, der bærer udviklingsomkostninger og produktrisiko

3. Konservatisme hos de myndigheder, der skal godkende komponenterne og hele byggeriet, da specielt brandkrav kræver lidt kreativitet og villighed. Det er også vores erfaringer fra feks. Passagerfærger.

4. Relativ kort tid fra et projekt starter til det skal stå færdigt. Dette gør det svært at få udviklet materialer, der opfylder gældende brandkrav samtidig med at materialeomkostninger holdes nede.

Jeg håber dette giver en idé om hvor vi står lige nu.

Ring gerne hvis du ønsker en supplerende snak om dette samt hvad der kan gøres for at ændre på tingenes tilstand.

Appendix 2: Construction Positioning

1 Research

ECTP-Denmark

ECTP-Denmark is a self-financed and open network under the European ECTP organisation (European Construction Technology Platform). A main objective is to support that the Danish construction industry benefits from the R&D resources of the 7th European Framework.

The European Commission has proclaimed that the 7th European framework can support no more than one third of each R&D project. Subsequently a main barrier is that the Danish Construction Industry has a very limited tradition for industry financed R&D. An essential activity of ECTP-Denmark is thus to coordinate research and development in a Danish context with special focus on SMEs and to work for a higher degree of industry financed R&D. All ongoing and future R&D projects can be included in the activities of ETCP-Denmark.

ECTP-Denmark has formulated the following R&D areas as spearheads in the Danish context:

1. Energy, indoor climate and ventilation
2. End-user value
3. Building production
4. Materials
5. Urban Development

Members of ECTP-Denmark are predominantly institutional players, (such as business associations, R&D institutions) but also large manufacturers of buildings components.

Building Lab DK

Building Lab DK is a part of Foundation Realdania's (www.realdania.dk) strategy for improving "The Future of Construction".

The aim of Building Lab DK is to cultivate innovation in construction and to help the industry to offer higher quality and greater value for money. Building Lab DK is particular focused on innovations related to mass-customisation and cross-sectional ways of working. Furthermore Building Lab DK works to improve coherence between the many initiatives already implemented by construction firms. The budget of Building lab is

Building Lab DK works by offering support to company-driven innovation consortiums. Financial support is based on a fifty-fifty principle; the participating firms will pay a minimum of 50% of the total innovation costs

The Danish Building Research Institute (SBi)

SBi is the Danish national building research institute. Until 2007 SBi was a government research institute under the Ministry of Economic and Business Affairs. Since January 1st 2007 SBi has become an institute under Aalborg University.

A primary task for SBi is to offer research based advice and communication to decisions-makers and professionals engaged in building and the built environment.

SBi has a staff of 100 and an annual turnover of approximately DKK 62 million.

The Department of Process and Innovation conducts research of relevance for nana-byg especially on ICT and new forms of collaboration, including strategic partnerships.

The Department of Building Design and Technology conducts research to improve building solutions, including research on Structural stability and safety assessments; Structural stability and safety assessments; Properties of building materials and components; Performance requirements; Durability and service life.

Department of Civil Engineering at the technical university of Denmark (BYG·DTU)

Department of Civil Engineering at the technical university of Denmark- BYG·DTU has approximately 162 employees (46 scientific personnel, 32 project employed scientific personnel, 48 technical and administrative personnel). In addition are approximately 25 external lectureships and 5 industrial PhD's.

The turnover is approximately 83 million DKK/year (2005) and is a combination of DTU funding covering the education and "free" research and external means from private funding, private companies, PhD projects, etc. The external funding constitutes more than 35% of the turnover

BYG·DTU conducts research and education in the fields of:

- Planning and Management of Building Processes
- Structural Engineering
- Construction Materials
- Geotechnics
- Building Energy and Services
- Innovation , ICT ,sustainability and integration are crosscutting themes.

Center for Management Studies of the Building Process

Center for Management Studies of the Building Process is a virtual research center at the Copenhagen Business School. The center is financed by the Foundation Realdania and the participating companies and institutions. The center consists of a network of researchers and projects that are located in physically separate institutions, but coupled through communication and joint activities.

The purpose of the research center is to create new knowledge about the organizing and development of the Danish building process and in particular to contribute to a more varied understanding of reality than what is currently characterizing the design, production, and training practice in the building sector. This vision we are going to pursue through empirical studies subsumed under five research themes and a number of research projects. The themes are:

1. Roles and identities
2. Innovation
3. Economies of construction
4. Knowledge and learning
5. Organizational models

The projects will focus on specific issues relevant in relation to the general research themes to which the projects will contribute with various input.

The approved technological service institutes (GTS).

Since WW2 the approved technological service institutes have played a mayor role in the technological infrastructure of Danish industry. These institutes have been especially important in the generation and diffusion of knowledge and competences to the SMEs which are traditionally weak in R&D. The GTS net consists of 6 institutes. [construction activities?]

CINARK

The overall objective of CINARK - Center of Industrialised Architecture is to strengthen the position of the school, the education and the architectural profession when it comes to the use and understanding of the architectural potential in industrialised building.

This includes its organisation, processes of manufacturing as well as design based building components. Through intensified research and education it is the intention to accumulate and communicate current knowledge in order to improve the dialog between architects and producers of industrial building products and constructions.

CINARK is a center under the Institute of Technology at Royal Danish Academy of Fine Arts, School of Architecture.

Danish Design Schools and Centers

On the Design School in Kolding and at Denmarks Design School in Copenhagen education of designers take place. The ambition for both is to be given university status in 2010. Education and knowledge distribution of new materials of interest for designers are an important function.

Denmarks Design School in Copenhagen offer education in areas as industrial design, clothing design, textile design, Ceramic and Glass design, Room and furniture design, digital communication, digital interaction, production design and visual communication.

Designschool Kolding provides training and education to 380 students, divided between the following institutes: Institute for Form & Theory; Institute for Fashion & Textiles; Institute for Visual Communication; Institute for Industrial Design & Interactive Media; Department of Ceramics

The Danish Design Centre is an independent institution under the Ministry of Economic and Business Affairs, which strives to enhance the use of design in the Danish business world, brand Danish design worldwide and increase the interest for design in the general public. The overall purpose is to contribute actively to value creation in Denmark and to ensure that Danish design remains a strong brand in Denmark and abroad.

2 Industrial organizations

The Danish Construction Association (Dansk byggeri)

The Danish Construction Association is a commercial and employers' organization for approximately 6.200 companies within the Danish construction industry. The member companies employ approximately 80.000 people.

The Danish Construction Association plays an active role in the dialog and shaping of the regulatory framework concerning the development of the industry .

Building Materials Industry (Byggematerialeindustrien.

The Building Matrial Industry is an association under the Confederation of Danish Industries. The objectives of the Building Materials Industry are to establish a framework for professional collaboration among colleagues in relation to construction products. To promote these objectives BI endeavours to:

Ensure an improved profile for construction products among the general public.

Make binding decisions and formulate views and opinions relating to the industry and towards politicians and authorities in areas and on issues that only concern this line of industry.

Reinforce solidarity and collaboration among members and the cooperation with the Confederation of Danish Industries.

Members of BI are potentially key players concerning building in nanotechnology in materials and component for the building industry.

The Danish Lumber Merchant Union Association

The Union is a central association of the firms of distribution and selling of building materials to the construction industry.

Danish Building Supply Association (Byggeleverandørforeningen)

The association has producents and agencies for imports of building material and components as members. Today about 60 members. A objective is to enhance the knowledge on the building sector, to secure a strong network for the members and to work for the interest of the menmbers. The association is members of Danish Construction and FEDIYMA, the Federation of European DIY Manufacturers' Associations.

Danish Association of Construction Clients

The Danish Association of Construction Clients is an interest group representing professional construction clients in Denmark. The association was formed in 1999 with the goal to influence and improve the Danish construction sector. The Clients is buyers of the products delivered by the Building and Construction sector.

Clients are key stakeholders concerning decisions of buying new nanobased funtionalities in Building.

Danish Association of Architectural Firms (DANSKE ARK)

Established in 1960, the Danish Association of Architectural Firms (DANSKE ARK) is the Danish association of private firms of consulting architects. Danske Ark's objective is to represent the commercial interests of practising architects and, in its capacity as impartial consultant to building clients, strengthen the position, quality level and professionalism of its member firms. About 650 ordinary and associated member firms, which - combined - employ more than 4500 persons.

The Danish Association of Consulting Engineers (FRI)

FRI is a trade association of Danish consulting firms providing consulting services, planing and project management on a technical-scientific basis. In addition, member firms provide services in economic as well as non-technical fields with delivery of the relevant systems involved.

Total turnover in the industry amounts to about DKK 7bn (€950 mn) in Denmark. The building and construction sector accounts for well over half of that amount, and the remainder derives primarily from the environmental, energy and IT sectors.

FRI’s member firms provide independent consulting services on market terms. FRI represents the majority of businesses in the industri. FRI’s member firms employ about 9,000 people in Denmark and over 5,000 abroad.

Danish facility Management Network

The Objective of the network is to facilitate development of the sector and the knowledge about facilities management, to enhance the cooperation between

praxis, education and research and to be a link to the development on the international scene. Today there are 150 members and include faciloities managers in private companies, constrators, consultants and suppliers for public firms and institutions.

A key actor concerning distribution of a heavy part of the functionalities, so far developed through nanomaterials.

TEQNIK, Danish Mechanical and Electrical Contractors' Association

The association is the fifth-largest trade/employers' organisation in Denmark, and thus the second-largest in the construction industry.
The association was founded by the Danish Electrical Contractors' Association ELFO and the Danish Plumbing, Heating and Ventilating Contractors' Association on 1 January 2002. Today, it represents around 3,000 mechanical and electrical contractors in the electricity and the plumbing, heating and ventilating industries – about 1,800 electrical contractors and about 1,200 plumbing, heating and ventilating contractors.

The member contractors cover a wide field and, in terms of size, range from the small single proprietorship to big mechanical and electrical contractors with more than 2,000 employees.

Labour Union – 3F

3F is the labour union for employed in Building and Construction. Besides negotiation about wages etc, risks and educational activities are important issues, which are taken care of by the union.

3 Europe / General

European Construction Technology Platform (ECTP).

The overall coordination of the EU policy on construction is performed by the European Construction Technology Platform (ECTP). Some of the overall objectives for the ECTP are1:

- The industrialisation of the construction process to significantly reduce construction costs and increase quality;
- The creation of safe and healthy working and living environments for European citizens;
- Participation in the work to streamline national and European legislation to create a truly common market for construction products and services;

1 see: http://www.ectp.org/presentation.asp

- Action to reduce the use of energy, materials, and other resources in construction and in the built environment

These objectives will be presented in further detail in the 'vision 2030 for the European construction sector'. The result of this paper should be a Strategic Research Agenda (SRA), consisting of specific roadmaps and strategies. These strategies should be implemented in detail in specific R&D programmes such as; the seventh framework programme of the European Community for research, technological development and demonstration activities (2007 to 2013), Eranet and Eureka.

ETCP has formulated the 7 following focus areas: Underground Construction, Cities and Buildings, Quality of Life, Materials, Networks, Cultural Heritage, Processes & ICT

Under the focus area 'Materials' nanotechnology is emphasised as techniques with the potential of creating a 'breakthrough' within the manufacturing of building materials. A main barrier to innovation is identified as the fragmentation of the research process, both on industrial and academic level.

ERABuild

ERABUILD aims at having a major impact on creating the European Research Area (ERA) in research on sustainable development in the construction and operation of buildings. A step towards this aim is planning and preparing a trans-national R&D programme in the area. A short term goal for the project is the development of a learning network of governmental organisations. The association origins from the ECTP organisation.

In Denmark representatives from EBST have the Danish leadership. Calls and facilitating actions are taken on different topics. New technologies is of interest for the Danish Erabuild.

EurekaBuild

The purpose of EurekaBuild is to improve innovation in the European construction sector by facilitating cooperation between research institutions and industry by stimulation the generation of R&D projects

4 Nordic Initiatives

NICe (Nordic Innovation Center)

The Nordic Innovation Centre is the Nordic Council of Ministers single most important instrument for promoting an innovative and knowledge-intensive Nordic business sector. It has no special focus on Building and Construction, which are seen as one between more important business sectors. The basic assumption is that each of the Nordic countries possesses knowledge, which through increased co-operation significantly will improve innovation capabilities and competitiveness for Nordic businesses. Today, the Nordic Innovation Centre is an important player in Nordic knowledge platforms within the areas of innovation policy, creative industries, biotechnology, food safety and innovative building & construction.

Establishing common Nordic knowledge platforms on strategically important areas give Nordic businesses access to the best knowledge possible and greatly enhance their innovation capabilities. It is believed that building common Nordic knowledge markets are vital to all Nordic business life, enabling us to compete in a global market which is becoming more and more knowledge driven. The total project portfolio of the Nordic Innovation Centre consists of approximately 120 ongoing projects and networks. Together with several hundred completed projects of great value to Nordic businesses, these projects involve the Centre in nearly all strategically important Nordic areas.

Nibcor

At the Nordic level the Nordic Council of Ministers has established a project, Nibcor, which have to establish activities for facilitation of joint research and development projects especially in the Building sector. Nibcor initiatives have focused upon themes as user-driven innovation, digitalisation of the building sector and the transformation of the sector.

E-CORE - European Construction Research Network

The Thematic Network E-CORE 'European Construction Research Network' has as general objective to promote the development of European networking in order to achieve a better co-ordination of efforts and a more rapid diffusion of results so as to ensure that research activity generates real innovation for construction and related industries.

By bringing together and collating results from European, national and regional RTD initiatives and following a pro-active Technology Watch approach, E-CORE seeks to become the electronic reference point in Europe for obtaining information on the state-of-the-art and the status of RTD in the construction sector. E-CORE further endeavours to facilitate dissemination of cutting edge technology and its implementation, to identify knowledge gaps and to advice on RTD strategies for the construction sector at the European level. As such, E-CORE would specifically contribute towards establishing a European Research Area as defined in the Communication of Commissioner Busquin on behalf of the construction industry.

European Council for Construction Research Development and Innovation - ECCREDI

The European Council for Construction Research, Development and Innovation (ECCREDI) was created in Brussels on 19 December 1995 with the signing of a Memorandum of Understanding by representatives of European construction related organisations. The European organisations participating in ECCREDI represent the principal actors involved in the construction sector: contractors, engineering consultants, architects and designers, product and material producers as well as research bodies. The aim of ECCREDI is to contribute to the competitiveness, quality, safety and environmental performance of the construction sector and to the overall sustainability of the built environment, by increasing the extent and effectiveness of construction research, technical and process development as well as innovation.

International council for Research and Innovation in Building and Construction - CIB

CIB is the acronym of the abbreviated French (former) name: "Conseil International du Bâtiment" (in English this is: International Council for Building). In the course of 1998, the abbreviation has been kept but the full name changed into: INTERNATIONAL COUNCIL FOR RESEARCH AND INNOVATION IN BUILDING AND CONSTRUCTION CIB was established in 1953 as an Association whose objectives were to stimulate and facilitate international cooperation and information exchange between governmental research institutes in the building and construction sector, with an emphasis on those institutes engaged in technical fields of research. CIB has since developed into a world wide network of over 5000 experts from about 500 member organisations active in the research community, in industry or in education, who cooperate and exchange information in over 50 CIB Commissions covering all fields in building and construction related research and innovation. CIB Members are institutes, companies and other types of organisations involved in research or in the transfer or application of research results. Member organisations appoint experts to participate in CIB Commissions. An individual also can be a member and participate in a Commission. CIB Commissions initiate projects for R&D and information exchange, organise meetings and produce publications. These meetings can be Commission meetings for members only or international symposia and congresses open to all. Publications can be proceedings, scientific or technical analyses and international state of the art report

Appendix 3: Architecture, Design and Nanotechnology

1 Positioneringindlæg: arkitektur og nanobyg

Introduction

In architecture there is a growing interest and awareness of the possibilities for using nanotechnology in the built environment. The emergence of smart paints and coatings that protect and clean glass and cladding, of new nano-optics in the form of high performance LEDs, of flexible polymer based photovoltaic technologies and of new types of sensors that can be directly integrated into the built edifice is challenging the way we use technologies in architecture. Rather than thinking technology as something ported into the building after its erection, these technologies are directly integrated into the material construction. Combined with traditional materials such as steel and glass, these composites, promise more sustainable and environmentally responsive materials whose strength and performance far supersedes which has come before. Smart materials, that incorporate state changes such as memory alloys and polymers, furthermore points towards the possibility of thinking architecture as a dynamic structure that is able to react to its environment and inhabitation.

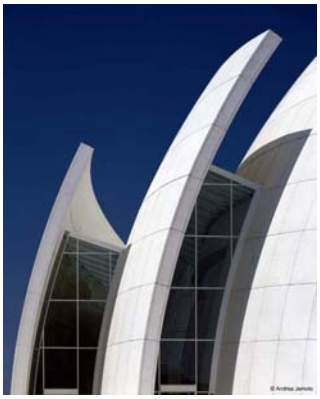

Fig 1: Richard Meier's Jubilee Church using nano coating on concrete panels

Fig 2: UN Studios LED façade on the Galleria Shopping Mall in Seoul.

Examples

The last 5 years has seen a proliferation of nanotechnology in the building industry. Through research initiatives such as Nano-House and Glass-House[i] but increasingly also through cases emerging from the building industry itself, architects are exploring the way that nanotechnology challenges and extends the design and realisation of the built environment. Nano-House, a case study developed at the University of Technology, Sidney, explores a combination of nanotechnologies. The metal roofing is coated with a radiating paint making the roof a cooling element. The glass is self-cleaning and it uses cold lighting systems (LEDs) as well as dye solar cells. In the Glass House, a collaboration with Pilkington Glass, the new self-cleaning Active Glass was tested. This has since been implemented in a series of commercial buildings such as the General Hospital in Carmarthen, UK. Other high profile projects using nano-coatings include Richard Meier's Jubilee Church in Rome and Herzog & de Meuron's Bond Street Apartment Building in New York. Experiments with LED lighting are also prolific. Here, architects use LEDs for their easy integration, their small size as well as their low energy absorption. In UN studio's façade for the Galleria Shopping mall, interactive LED lights are fixed to the façade creating a display at city scale. In Wilkinson Eyre's Tensigrity Bridge at the National Building Museum in Washington D.C., LEDs are to be integrated into structural glass tubes, interactively switching on and

off as load bearing changes[ii]. However, the use of nanotechnology in composites (such as nano-fibres in concrete[iii]), nano-sensors remain and smart materials that can state change remains at a research stage.

In Denmark, the use of nanotechnology remains very scarce. In our interviews with a section of the country's leading design offices[iv] we found only two examples of offices using nanotechnologies. Dorthe Mandrup Architects used self-cleaning glass in Jægersborg Vandtårn, while Lundgaard og Tranberg used TCnano's gel compound for sealing a cast concrete floor surface. Many offices explained that they were in the process of exploring the use of coatings, LED lighting but that as with the use of commercially available self-cleaning glass the main obstacle for using nanotechnologies is price and knowledge about available products and their detailing.

Problems and obstacles

Whereas there is a clear interest in nanotechnology within architectural practice there is a lack of awareness of the scope and possibility for its implementation and use. Nanotechnologists are aware of the potential application of nanotechnology in the building industry, but there is little information available for architects about precedents[v]. The Danish architects we contacted all expressed that the main problem with these technologies is their exponential increase in cost. As explained by Holger Bak from Palle Leif Hansen Architects an average square metre of glass can cost around 1.000 DDK while coated glass can cost up to 12.000 DDK. This twelve fold increase is most often refused by the developer as the budget of maintaining a building rarely coincides with that of its construction.

Fig 3: Lundgaard og Tranberg's Industri Kollegiet in Copenhagen uses a TCnano's gel compound for floor sealing.

Further obstacles are the lack of detailed information about products and their availability but fore mostly confusion about what nanotechnology really comprises. Architects are aware of nanotechnology as a buzzword but have little understanding of its actual scope. This is a problem addressed with in the international community through web based knowledge banks such as nanoarchitecture.net and nanosearch.com[vi]. There are few research initiative focussed on nanotechnology and the built environment[vii] and we have found *none* that explore the architectural potentials of this new technology.

Fig 4: Malcolm Carver's Beach House from 2005 in New South Wales, Australia uses self-cleaning glass.

As expressed by Peter Kjær at Lundgaard and Tranberg Architects there is a need for a unifying organisation that could collect information, documentation as well as samples about new technologies and nano-products specifically for architects and make them available to the profession. The interviews revealed a general desire and interest in knowledge pooling and sharing experiences both within the profession but also with research and industry.

Potentials

Nanotechnology represents a departure in the way that architects learn about and integrate new materials in their practice. As expressed by Addington in her article *Smart Materials and Technologies*[viii]: "Architects have conceptually been trying to follow the traditional model by which "new" materials have long been introduced into architecture, initially through simply 'replacing' conventional materials, then through highly visible show pieces (often novelty effects such as thermo-chromic chair backs and electro-chromic toilet stall doors) and later through high profile "demonstration" projects." Addington calls for a change in approach as these new materials don't replace but challenge and change the way that architecture could be imagined. "Whereas standard building materials are static in that they are intended to withstand building forces, smart materials are dynamic in that they behave in response to energy fields. This is an important difference as our normal means of representation in architectural design (through orthographic projection) privileges the static material".

There as such is a call for a research unit that explores the direct applications of nano-technologies in architecture; the structural and environmental consequences, as well as the need for opening up for design investigations into the functional, programmatic and aesthetic challenges that these technologies can bring about. As associate partner Lars Steffensen from Henning Larsen's Tegnestue says he foresees a great span of new possibilities that opens up for a new formal language radically changing the performance of architecture[ix].

Danish design and architecture are strong cultural exports that can gain from an expansion of its expertise. To maintain and develop our position as high profile designers with a strong innovative approach to materials it is important that research, practice and industry meet in the development of a nano approach to building.

Fig 5: Henning Larsens Tegnestue's Institute for Diplomatic Studies, Riyadh. Speculative project exploring complex glass surface that could use nano-glass.

Endnotes

[i] Nano-House and Glass-House are research projects lead by Carl Masens at the Institute for Nanoscale Technology, University of Technology Sydney (UTS) and architect James Muir. The projects have been undertaken in collaboration with CSIRO, Arups and Pilkington Glass.

http://www.nano.uts.edu.au/about/australia.html

http://www.arup.com/australasia/newsitem.cfm?pageid=5204

[ii] The project was developed in collaboration with Cecil Balmond, Arup, and was prototyped and demonstrated at the Venice Biennale 2004.

[iii] We interviewed concrete specialist Gaurac Biswas at Arup Engineering who explained that Arups are not implanting nano-concretes at the given time. He also said that he was not aware of any building applications of nano-reinforced concretes anywhere in the world.

[iv] To obtain information about the use of nanotechnology in the Danish architectural scene we interviewed a sample of 10 Danish architecture offices. Please see interview materials for more information.

[v] In our search of architectural journals and publications we found very few examples except for Michelle Addingtons and Daniel L. Schodek overview “Smart Materials and Technologies in Architecture”, 2005, John Johansen, Nanoarchitecture: A New Species of Architecture, 2002, Axel Ritter’s Smart Materials in Architecture, Interior Architecture and Design, 2007 as well as articles in A+U Feature Structure and Materials (05:01); Architecture Australia, Housing the Future, Jan/Feb 2005.

[vi] This site is still in process of being constructed.

[vii] Please see Mette Geiker’s section on international nano-construction initiatives.

[viii] In A+U Feature Structure and Materials (05:01)

[ix] Henning Larsens Tegnestue is an international office with many projects abroad especially in Dubai and the Middle East. In these extreme climates nano$technologies and smart materials could be used for the control of heat gain and natural ventilation as well as solar energy.

Appendix 4: Environmental risks

This appendix contains:

An overview of governmental initiatives in relation to environmental risks and nanotechnology

An identification and discussion of different environmental risk areas

1 Governmental initiatives in relation to risk and nanotechnology

1.1 Ministry of Employment

The following evaluation of the policy of the Ministry vis-á-vis nanotechnology and its use in the building industry builds on desk research on the net. At least three units within the resort of the ministry is activily work with the work environment aspect of nano technologies in general and also the relation between nanotechnologies and the impact on work environment within the building sector. This is :

- The Danish Working Environment Authority (Arbejdstilsynet)
- National Research Centre for the Working Environment (Det nationale kompetencecenter for arbejdsmiljø, tidl. Arbejdsmiljøinstituttet)
- The Danish Health and Safety Research Fund (Arbejdsmiljøforskningsfonden)
- The policy can be characterized as composed of three components;
- knowledge gathering and dessimination (website, information pages)
- research within nano toxicology
- participation in public committee formulating recommendations for the authorities policy

It is thus characteristic that little practical regulation of work environment is carried out.

1.2 The Danish Working Environment Authority

Where The Danish Working Environment Authority (DWEA) is responsible for a quite active inspection policy in the building, because of a high frequency of occupational accidents and illegal safety conditions, this activity does not apper to encompass “finer nuances” as handling of nanotechnology could be seen as. At an inspection action in the beginning of January 2007 DWEA visited 204 building sites. At 112 of the sites DWEA had to intervene in 174 cases vis-á-vis work within the chosen focus areas. In 114 cases DWEA had to stop the work at the site. These figures underlines the orientation and preoccupation of DWEA of other work environment issues than nanotechnologies. The Danish Working Environment

Authority carried out a strategy process in 2005. In this process nanotechnology was incalculated as a future technology to follow. It was however evaluated as les important than information technology (faktaark Fremtidens arbejdmiljø). Quote:

“ Hastig teknologisk udvikling:

Særlig på de informations- og kommunikations-teknologiske, bio-teknologiske og nano-teknologiske områder må der forventes en markant teknologisk udvikling. Ikke mindst udviklingen inden for informations- og kommunikationsteknologien forventes at slå igennem også i arbejdslivet allerede i perioden indtil 2010 - fx i form af helt nye trådløse “workstations”, fx mobiltelefoner med pc/tastatur, internet- og netværksopkobling mv. i én transportabel enhed.

And the impact on work environment was evaluated as possible both positive and negative (Arbejdsmiljøets fremtid) Quote:

“Evt. nye risikofaktorer som følge af den teknologiske udvikling

Udviklingen inden for informations- og kommunikationsteknologi samt bio- og nanoteknologi kan føre til udryddelse af nogle arbejdsmiljøproblemer og opståen af andre nye arbejdsmiljøproblemer.”

In this strategy it is again more ”heavy” work environment problems such as occupational accidents which is weighed the most.

1.3 National Research Centre for the Working Environment

The National Research Centre for the Working Environment (NRCWE) has initiated research within the area of nanotoxicology. As part of this a status of existing research was carried out on 2004. From this research it appeared that 70 different types of nanotechnology is described in the latest 300 research articles. NRCWE communicates one epidemiological investigation documenting that German carbon black workers have doubled their death- incidence for lung cancer and another cronical lung disease. Moreover experiments with rats have shown increased symptoms of inflammations related to small particles (20 nanometer as compared to 250 nanometers), to carbon black, to carbon nanotubes and to the carbon molecule , the socalled football molecule.

NRCWE has participated in governmental committees evaluating the future prospects of nanotechnology (Teknologirådet og teknologiskfremsyn). Moreover the NRCWE has developed informative material both as webpages and as information sheets (Informationsark no 16).This material include measures to take in production processes and in laboratories. NRCWE estimates that around 50 enterprises is prepares or carrying out nanotechnological production.

From NRCWE website material it appears that nanotechnological content in building material and – components is known to NRCWE. The effort is however designed in a general way targeting the entire labour market. The information is thus not concret enough to link to practice on the building site.

1.4 The Danish Health and Safety Research Fund

The Danish Health and Safety Research Fund, (DHSFR, Arbejdsmiljøforskningsfonden) has prioritised nanotoxicology as research area in

their strategy for 2007-2007. In the call from the fund for 1st of march nanotechnology is part of the theme Substances and materials (Stoffer og materialer). The fund argues that there is a lack of knowledge on exposure of chemical substances and their work environment impact on Danish workplaces. There is a need to bette understand the relation between chemical exposure and cancer, allergic diseases and skindiseases related to “wet work”. However the fund continues:

”Nanoteknologi er et nyt område og viden om arbejdsmiljørisici er begrænset. Eksponering og risiko for eksponering med ultrafine partikler formodes at få stigende betydning ved produktion af nye produkter. Når partikler bliver så små, at de kommer ned i nano-området kan partiklerne ændre karakter og få andre egenskaber end større partikler af det samme kemiske stof. Partiklernes sundhedsfarlige egenskaber kan også ændre sig og det vil få betydning for sikkerhed og sundhed ved produktion og anvendelse af de nye produkter. Overordnet set mangler der gode metoder til at vurdere ultrafine partiklers sundhedsmæssige egenskaber.”

Upon this policy statement the fund calls for research within 11 areas of substance and materials. Three is directly aimed at nano. Those are

- Identifikation af nanopartikler i felten eller i arbejdsopgaver i laboratorieopstillinger
- Viden om toksikologisk relevante fysisk-kemiske egenskaber, herunder støvegenskaber (støvdannelse, genophvirvling, levetid) for forskellige nanopartikler.
- Forebyggelsesstrategier og metoder herunder værnemidler og deres effektivitet over for nanopartikler.

It derives that research within toxic effects of nanotechnologies will commence in 2007. This research might be directed towards the use of nanotechnology in construction, but this is just one area out of many.

1.5 Other Initiatives

It should be mentioned that a recent report from the national council of technology assessment (**Teknologirådet**) have evaluated the work environment risks as well. Moreover a Nano foresight took thse types of risks on board as well. The authorities within the ministry of employment participated in those. Also as mentioned elsewhere the research committee **NABIIT** funded nanotoxicolical research at the end of 2006. The Organisation “ **Bolius**” (financed by Realdania and targeting private consumers) have at their webpage evaluated two types of paint with nanotechnology and discuss the paint properties in terms of diminished bacterias, smell in the inner climate and the work environment effect. The products are Airfresh Compound (Puds), Airfresh Paint from Maxit and the products Capasan 1010 Caparol Electro Shield from Rockidan. Health effect are related to the production processes. If the paint is sprayed on the items this might imply a risk. Also scraping down nanopaint at a later stage as part of renovation mightr create particles evaluated Bolius on the basis of manufacturers and NRCWE-information.

Summing up, There is a growing effort of information, knowledge gathering and research within the auspices of the ministry. Since the labour inspection and

the Danish work environment regulation in general are built on a principle of the enterprises self regulation and since other work environment problems are prevalent (i.e occupational accidents) it is no surprise that practical regulation is less developed. We saw moreover that the effort towards nanotechnology still is general and cross sectoral. A voluntary registration system of enterprises using nanotechnology such as the implemented in UK and US does not exist in Denmark.

2 Risks areas

Der kan peges på tre grundlæggende risikområder, der bør overvejes (Meili 2006, Belbus et al 2006)

- arbejdsprocesser
- det eksterne miljø
- forbrugere/produkt

Forskningsbehovet knyttet til risici har i hvert fald to sider. Den ene er forskning i de virkningsmekanismer, der får nanoteknologi til at spredes i menneskets krop og i naturen. Der er mange steder i verdenen forskning af denne type (Baun, Rice University m.m.).

Den anden er forskning i erfaringer med praktiske anvendelser af nanoteknologi og i forskellige regulerende foranstaltninger (sikkerhedsudstyr, registrering mv.)

Meili (2006) vurderer at det er i arbejdsmiljøet i produktionen (første ovenfor) at den regulerende indsats først skal sættes ind. Overvejelsen er at nanoteknologi endnu anvendes i små mængder og det derfor er menneskets udsættelse man skal sætte ind overfor først (Schmid 2006). Aitken et al (2006) omtaler således status i England sådan her

"….relatively few companies in the UK are identifiable as NM manufacturers, the main emphasis being the bulk markets in metals and metal oxides, and some niche markets such as carbon nanotubes and quantum dots. NM manufacturing in the UK does not reflect the global emphasis on fullerenes, nanotubes and fibres"

Og videre

"While several companies are including NMs in their products, only a few (e.g. manufacturers of paints, coatings, cosmetics, catalysts, polymer composites) are using nanoparticles (NPs) in any significant quantities"

Nanopartikler kan optræde som frie luftbårne partikler fx i udstødningsgasser fra biler, men også opslemmet som partikler i væsker og emulsioner som fx hudcreme eller i strukturer. Teknologirådet (2006) skriver at partikler på nanoskala kan være farlige, hvis de har mulighed for at trænge ind i eller komme tæt på celler. Hvis nanopartiklerne udledes i luft eller vand vil de agglomerere (klumpe sammen). Hvor hurtigt vil variere med partikelkoncentrationen samt gassernes og vandets kemiske sammensætning. Nanopartiklerne og deres agglomerater kan holde sig svævende i meget lang tid, men sætter sig på nemt på over-flader, hvorfra de kun vanskeligt frigives. I nogen tilfælde vil nanopartikler kunne frigøres fra sammenklumpede partikler, fx i lungevæsken hvis de er inhalerede, selvom de er indåndet som agglomerater. Hvis overfladen er tilgængelig kan sammenklumpede partikler stadig udvise særlige nanoegenskaber, men i mange tilfælde vil de forsvinde. De største risici er derfor forbundet med nanopartikler, som er specifikt fremstillet til ikke at klumpe sammen eller hæfte sig på overflader, eller som af andre årsager har

tilsvarende egenskaber. Der til disse mekanismer sundhedsrisikoen er knyttet. Det antages almindeligvis at virkningen på menneskekroppe kan sammenlignes med den fra luftforurening (Teknologirådet 2006).

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